Economics of Ideas, Science, and Innovation

Class 1: Course Overview & Macroeconomic Foundations

Ben Jones, Kellogg / Northwestern
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Course Outline

Class 1	Course Overview and Macroeconomic Foundations	November 1	Benjamin Jones
Class 2	Open Science as an Economic Institution	November 8	Matt Clancy
Class 3	Innovation Policies, including the US Patent System	November 15	Heidi Williams
Class 4	Contracting and Control Rights for Innovation	November 29	Pierre Azoulay
Class 5	Research Opportunities, Data, and Methods	December 6	Heidi Williams
Class 6	Labor Markets and the Supply of Innovators	December 13	Ina Ganguli

Class 1

- **Why an "Economics of Ideas"?**
- The Nature of Ideas
- Macroeconomic Foundations

For most of human history, the average person has not been much more prosperous than their ancestors….all this changed beginning in the late 18th century

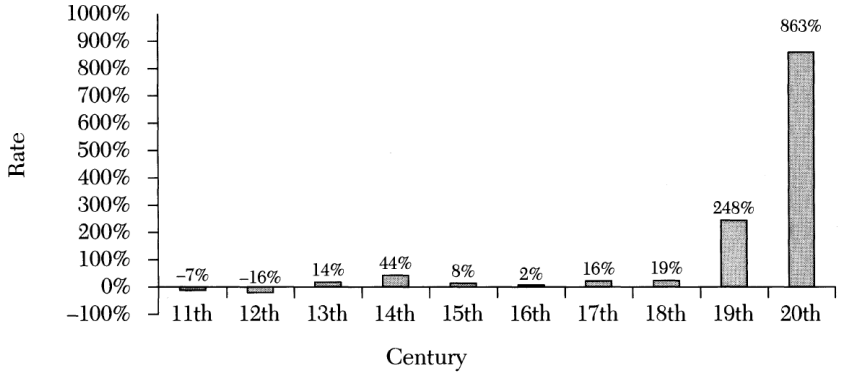
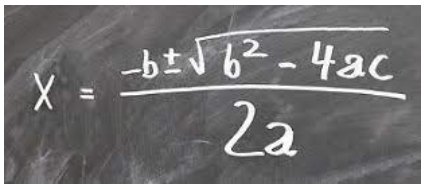


Figure 1. Growth in Real World Per-Capita GDP by Century.
Source: J. Bradford DeLong 2000.

- It seems almost self evident that the advance of "ideas" is key. See, e.g., Mokyr (1990) "Lever of Riches" for a history of ideas and their impact.

Why an 'Economics of Ideas'?



UNITED STATES PATENT AND TRADEMARK OFFICE
uspto

NIH
National Institutes of Health

hhmi
Howard Hughes Medical Institute

ALFRED P. SLOAN FOUNDATION

NSF

Argonne NATIONAL LABORATORY

DARPA

CERN

Why an 'Economics of Ideas'?

- The advance of ideas informs central phenomena
  - The path of economic prosperity
    (income, health; inequality)
  - The dynamics of markets, industries, trade
  - The role of institutions and policy

- Ideas are a special form of good. Idea production can be understood through distinctive economic, institutional, and sociological features.

- Idea production interfaces with many forms of market failure, pointing to key roles for public policy

Class 1

- Why an "Economics of Ideas"?

- **The Nature of Ideas**

- Macroeconomic Foundations

Ideas are Special Goods: An Introduction

Non-rivalry | Excludability

Cumulativeness | Uncertainty

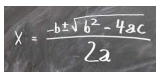
All underpinning market failures.

- The online course will use these features to understand major phenomena and several special institutions (e.g., intellectual property, universities, R&D tax credits…)

Ideas are Special Goods: Non-Rivalry

- Ideas are *non-rival* goods
  - Unlike most goods, the use of an idea by one party does not preclude its use by another party

Rival good



Non-rival good

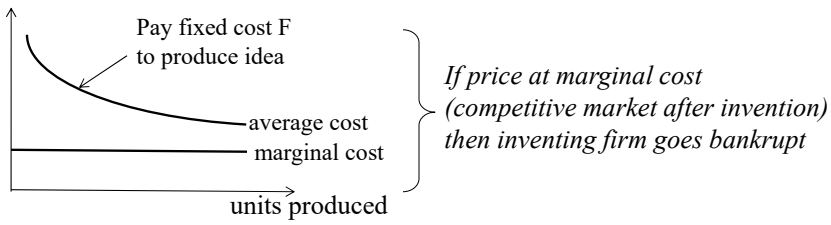
Non-rivalry:
- Algebra
- Germ theory of disease
- Assembly line
- Chemical process
- Regression
- CRISPR

- This property quickly leads to *market failures*

Ideas are Special Goods: Non-Rivalry

❖ *Non-rivalry* suggests that markets underinvest in new ideas

- *Spillovers:* Hard for innovator to capture full benefit of ideas
- *Increasing returns to scale:* hard to produce idea (fixed cost, possibly very large) but easy to copy (non-rival)



Ideas are Special Goods: Excludability

❖ Ideas may (or may not) be *excludable*
- Excludability: can you stop others from using something?
- Excludability is a source of *market power* (and thus private return on investment)

- Excludability depends on institutions and technology
  - *Institutions.* The patent system provides patent holder the right to exclude others from using an idea for a fixed period of time in exchange for disclosure of that idea to the public domain. Other intellectual property forms include copyright, trademarks, non-competes.
  - *Technology*. Ideas may be excludable without IP (secrets, cryptography, control of complementary inputs)

Ideas vs Other Goods: Examples

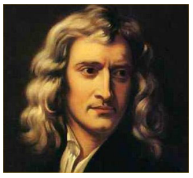
	Non-Excludable	Excludable
Non-Rivalrous	Basic Research, Calculus, National Defense	Satellite Radio, Patented Ideas
Rivalrous	Fish in Ocean	Lawyer services, Airplane seat

❖ Need special institutions to support idea creation. Consider:
- Intellectual property provides ex-post excludability
- Public agencies (e.g., NIH) provide ex-ante funding

Ideas are Special Goods: Cumulativeness

❖ The production of ideas is associated with spillovers -- across time, location, industries, technologies, etc

❖ Ideas are *cumulative* -- spillovers across time
- *"If I have seen further, it is by standing on ye shoulders of giants" (Newton)*

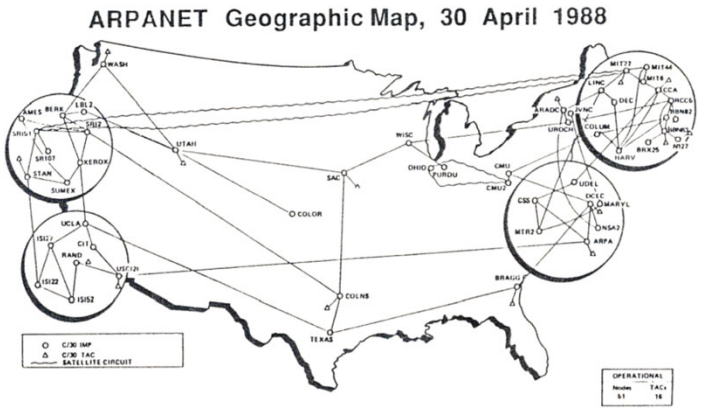


❖ This cumulative process seems largely unpriced
- Do we pay Newton for the use of calculus?
- How do we pay Tim Berners-Lee for the WWW?

❖ Implications for
- Social welfare / policy
- Strategic interaction
- The nature of creativity itself

Ideas are Special Goods: Uncertainty

Could you have foreseen the value of ARPANET when it was first developed?



Uncertainty is fundamental to the production of ideas and innovation…

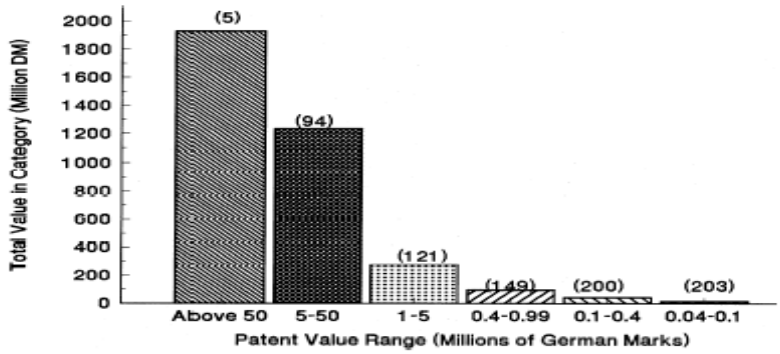
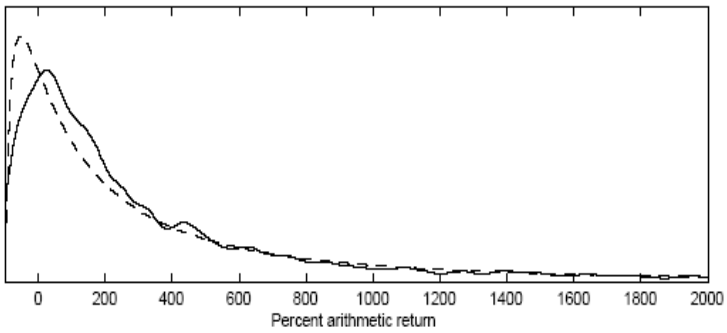


Fig. 1. Distribution of German patent values.

Among more than 750 *patented* inventions, 5 were collectively worth more than 1 billion DM, more than 50% of the total value of the entire sample!

Scherer and Harhoff, *Research Policy*, 2000

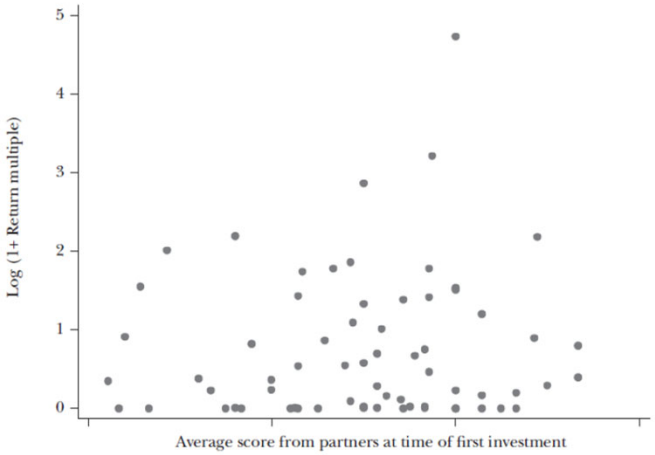
Conditional on being *funded* by VCs, a very small proportion of the total returns to VC are realized by a small number of investments.



Cochrane, *JFE*, 2005

Even close, incentivized observers (i.e., the VCs) don't know what will happen…

B: Correlation between Scores and Outcomes



Note: The labels on the horizontal axis have been suppressed to maintain the confidentiality of the investor's rating scale, but lower predictions were on the left and higher predictions were on the right.

Kerr et al., JEP 2014

Not simply a matter of traditional risk, the inability to forecast innovation seems to be fundamental (Rosenberg)

	Bell Labs Development of the Maser & Laser: "Bell's patent department at first refused to patent our amplifier…for optical frequencies because…optical waves had never been of any importance to communications and hence the invention had little bearing on Bell System interests" (Charles Townes, Nobel Laureate)
	Bell - Western Union Patent Agreement of 1878: Western Union will agree to stay out of the telephone business if Bell agrees to stay out of the telegraph business

Nate Rosenberg's Dimensions of Uncertainty

Can think of as a lack of foresight (not just risk)

- Initial technology is developed for a narrow application
- Little understanding of potential applications or uses
- Dependence on the emergence of complementary innovations and/or the emergence of entirely new technological systems
- Inability to imagine how to satisfy human needs in a novel way

c.f., "Merton multiples" and "births in time" (Merton 1961)
c.f., the early years of "general purpose technologies"

Related Note on Research Methods: Sampling

- Highly convex payoffs suggests somewhat peculiar focus. In studying invention/ innovation/ basic research, there is substantial interest in upper tail "outliers"
  - Highest-value patents
  - Home-run papers, "star" scientists, and prizes (e.g., Nobel)
  - Tech entrepreneurship

- Conversely, studying median inventors, entrepreneurs, or researchers may not be representative for outcomes of interest

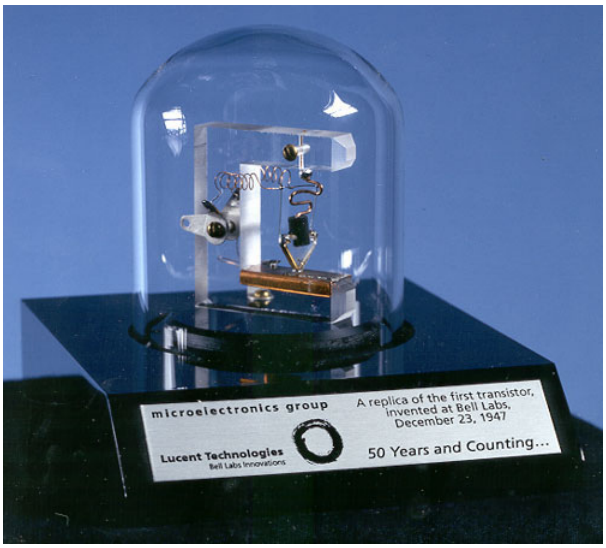
- In empirical research on ideas/innovation, it can be good therefore to either examine the census (or a random sample thereof), but also good to emphasize the upper tail

Uncertainty and the Market for Ideas

- What should the "price" of a given idea be?
  - The main determinant of "willingness to pay" for a traditional economic commodity is buyer's *ex-ante* information about the characteristics of that good. The correct willingness-to-pay for an idea therefore depends on *knowing* the idea
  - At which point one does not need to pay for it!

- Figuring out the "price" for an idea requires information that intrinsically reduces its value
  - N.B.: Not simply "information asymmetry" of the traditional kind, but a more fundamental consequence of inappropriabilty that limits transactions in the market for ideas

Uncertainty meets Organizational Design



Example: Organizations for Basic Research

- Important link between *cumulativeness* and *uncertainty* about downstream applications for understanding org design.

- What is the appropriate organizational form to encourage basic research? An introductory view:

- The Industrial Lab (e.g., Bell Labs, Google X)
  - Nelson's "finger in many pies" (Nelson 1959). Integration downstream essential to monetize uncertain outcomes from basic research (industrial lab model). Scope is key.

- The University (e.g., outputs like ML, CRISPR)
  - Public funding, embracing public goods model. Different set of organizational rules, norms, personal motivations.

The Nature of Ideas: Private vs. Social Returns

- The nature of ideas suggests many market failures
  - The social returns to innovation may then differ substantially from the private (market) return.
  - If so, room for institutions and policy interventions
- But how big are the social returns to innovation? Are markets a little off or way off? Do we really underinvest?

The Social Returns to Idea Creation Take 1: Bloom, Schankerman, Van Reenen 2013

- How do BSV attempt to calculated the social returns to R&D?
- What types of spillovers is their method is suited to address?
- What types of spillovers or aspects of R&D is their method not suited to address?

Class 1

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A Remarkable Fact: Economic Growth in the Long Run

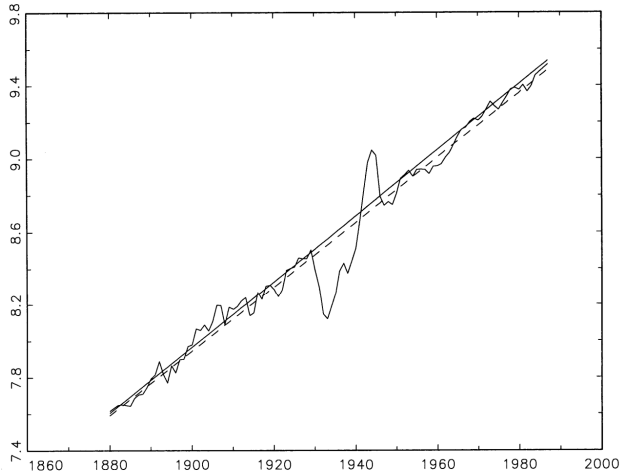


FIGURE I
Per Capita GDP in the United States, 1880–1987 (Natural logarithm)
Source. The data are from Maddison [1982, 1989] as compiled by Bernard [1991]. The solid trend line represents the time trend calculated using data only from 1880 to 1929. The dashed line is the trend for the entire sample.

Explaining Economic Growth: Three Facts

❖ What are we trying to explain?

Fact #1: Exponential, steady-state growth in per-capita income

❖ What other facts discipline our explanation?

Fact #2: The real rate of return (r) to capital does not trend

Fact #3: The physical capital share of income (rK/Y) does not trend (and is ~1/3)

❖ Notable implication of Facts 2 and 3

- *K/Y* is constant over time
- Therefore, *K* and *Y* grow at same rate

Ideas and Economic Growth: Overview

❖ How can we explain Fact 1 while maintaining Facts 2 and 3?

1. Can we explain growth purely from capital accumulation?
   Answer: No. (Solow)

2. What might ideas do for us?
   Answer: Explain growth. (Solow)

3. So how can idea creation be brought into the model?
   Answer: Market power. (Romer, Aghion/Howitt, and others)

Can we Explain Economic Growth with Capital Alone?

❖ Assume a (Cobb-Douglas) production function

$$Y = K^{\alpha} L^{1-\alpha} \Leftrightarrow y = k^{\alpha}$$

where second variant is per-capita ($y=Y/L$, $k=K/L$)
Observation: $\alpha = rK/Y \quad so \ \alpha \approx 1/3$

❖ Toolkit: To get growth rates (1) take logs and then (2) differentiate with respect to time

$$(1) \ln y = \alpha \ln k$$

$$(2) \, g_y = \alpha \, g_k \ \ (i.e., \ \dot{y}/y = \alpha \dot{k}/k)$$

Can we Explain Economic Growth with Capital Alone?

❖ <u>Problem</u>. Production function says $g_y = \alpha \, g_k$

But Facts 2 and 3 => *k/y* is constant => $g_y = g_k$

Therefore, with $\alpha < 1$, this model can only explain Facts 2 and 3 if

$$g_y = g_k = 0$$

But this abandons growth! We have lost Fact 1, which is what we really want to explain.

Intuition: Diminishing returns to capital, and reliance on capital, would require capital growth > income growth. But we don't see this in practice.

A Solution? What Ideas Might Do For Us

- Let's add a new input to production, call it "A"

$$Y = K^{\alpha}(AL)^{1-\alpha} \Leftrightarrow y = A^{1-\alpha}k^{\alpha}$$

- Take logs, differentiate with respect to time

$$g_y = \alpha g_k + (1-\alpha) g_A$$

- Recall that Facts 2 and 3 => *k/y* is constant => $g_y = g_k$
  Therefore,

$$g_y = g_k = g_A$$

- Great! We can grow now. Meeting facts 1, 2, and 3.

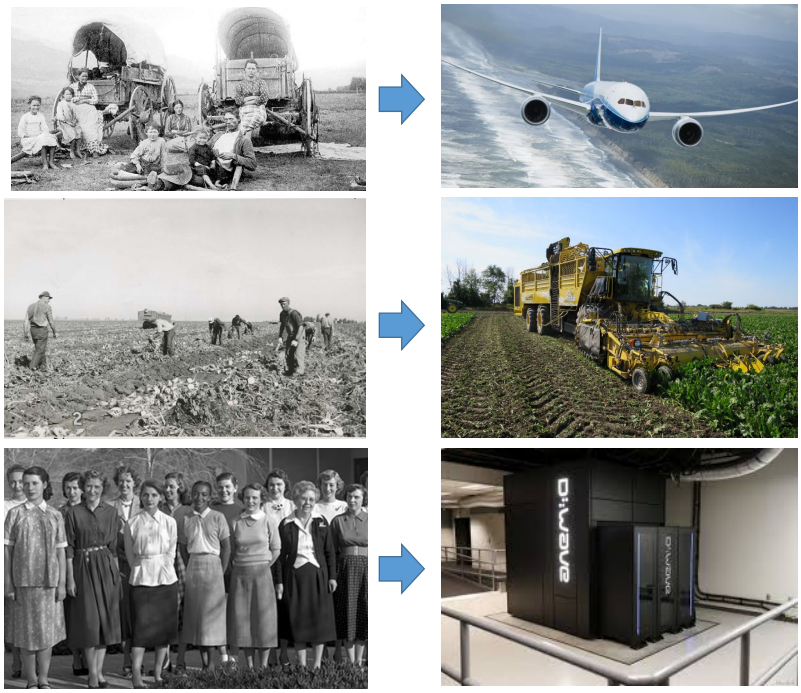
- Intuition: Growth in "A" overcomes diminishing returns to capital.

A Solution? What Ideas Might Do For Us

- It is "A" growth that drives growth. Key contribution of Solow.

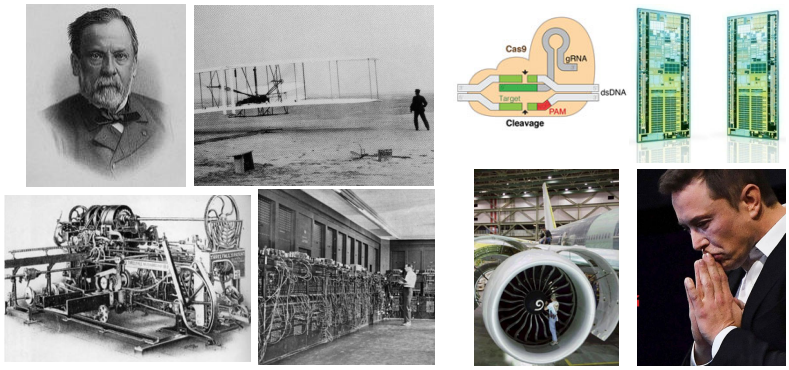
- But our solution is also a mystery.

- Remaining problems:
  - What exactly is A?
  - Why does A grow?



A Solution? What Ideas Might Do For Us

❖ One natural interpretation is that A growth represents advancement of "ideas". Ideas may, e.g., raise quality of physical capital (typewriters to computers) or human capital (quality of the raw labor input, L)



❖ How can we incorporate idea production into a growth model?

Returns to Scale and the Challenge of Ideas

❖ Observe: We like *constant returns to scale* (CRS) production functions by a replication argument

$$\lambda Y = F(A, \lambda \mathbf{X})$$

For example, Cobb-Douglas has property that $\lambda Y = (\lambda K)^{1-\alpha}(A\lambda L)^{\alpha}$

CRS implies that $Y = \sum_j \frac{\partial Y}{\partial X_j} X_j$

❖ <u>Problem</u>: With *competitive markets*, inputs are paid their marginal products:

$$p_j = \partial Y / \partial X_j$$

But then $Y = \sum_j p_j X_j$

So that we have no income (Y) left over to pay for A

Returns to Scale and the Challenge of Ideas (cont'd)

❖ Implication: An <u>impossible trinity</u>: can't have (simultaneously) (i) perfect competition, (ii) CRS, and (iii) people being paid for ideas

❖ <u>Solution #1</u>: Drop requirement (iii). One version (the so-called "AK model") makes idea growth an unintentional side-effect (spillover) from capital accumulation. No one pays for ideas.

- See C. Jones (JPE 1995) for macro-empirical evidence against an AK model. Also, at a micro level, it's obvious that many people *are* paid for ideas. We don't want to drop (iii).

❖ <u>**Solution #2</u>: Drop requirement (i). It's clear that perfect competition is not a great assumption – market power is common. Moreover, we have explicit institutions (patents, etc) that give market power to inventors. This seems more promising…yet modeling it proved quite elusive for three decades

The Market Power Solution

- Consider the Romer (1990) set-up

Idea Producers → Intermediate (capital) goods producers → Final good producers

Idea Producer: Monopolist owner of any idea produced. Uses this *monopoly power* to extract rents from the intermediate producer who uses the idea in production.
Intermediate Good Producer: Just willing to pay for idea. How can they afford to pay for it? We give the intermediate producing firms *market power*, so they can earn rents with which to pay for the ideas.
Final Good Producer: Competitive, buy intermediate goods at the (marked up) price the intermediate goods producers charge.

The Market Power Solution

- Steps of the argument

Idea Producers → Intermediate (capital) goods producers → Final good producers

1. *Intermediates market*: What is demand and supply? This defines prices and profits that intermediate producer receives.
2. *Ideas market*: Idea producers capture these profits through the patent they hold on the idea the intermediate producer uses.
3. *Labor market*: idea producer wage must equal wage in final goods sector. This pins down labor allocation between production work and idea work.
4. *Growth*: Knowing how much effort is put into idea production, we derive the growth rate.

What Do We Achieved?

❖ Ideas production is now endogenous
- We can examine idea production by replacing (i) perfect competition with market power, while maintaining (ii) CRS production functions for non-idea inputs and introducing (iii) payments for innovators. This seems like a useful framework.

❖ The economy is now fundamentally inefficient
- Monopoly pricing of ideas => ideas are under-utilized. Further, inventors under-produce ideas because they don't capture full consumer surplus from idea's implementation.
- More novel and potentially critical efficiency issues follow from the shape of the ideas production function
  - Recall cumulativeness. A researcher's output may unleash future possibilities for which the researcher is not compensated -- a potentially critical form of inefficiency.

What Have We Not Achieved?

❖ Among other things, neither (i) a deep understanding of the idea production function or (ii) a realistic appreciation of market structure and incentives
- For example, the endogenous growth framework replaced the statement

$$\frac{\dot{A}}{A} = g \quad \text{(Solow)}$$

with the statement

$$\frac{\dot{A}}{A} = \delta L_A \quad \text{(Romer et al.)}$$

❖ As a specific insight into idea production, this is very modest!

❖ Can we push forward on the macroeconomic viewpoint while beginning to bridge toward microeconomic features and data?

The Knowledge Production Function: Initial Approach

❖ Romer (1990), Aghion & Howitt (1992) et cetera assumed

$$\dot{A} = \delta A L_A$$

Inputs are (1) effort (L_A) and (2) current stock of ideas (A)

❖ Implication: growth rate follows the *level* of innovative effort

❖ Is that reasonable?

Scale Effects on Growth?

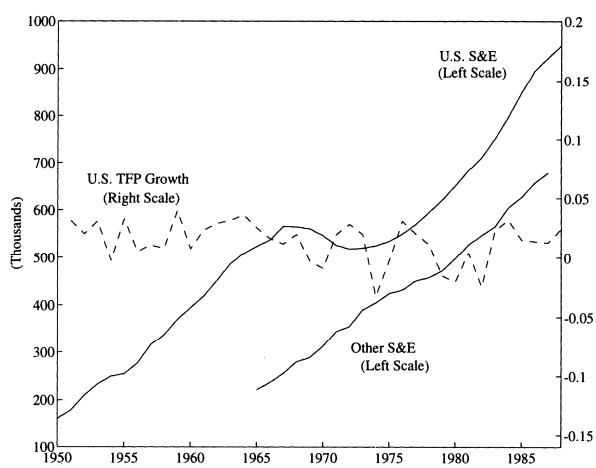


FIG. 1.—Scientists and engineers engaged in R & D and U.S. TFP growth. Source: The number of scientists and engineers engaged in R & D is taken from National Science Foundation (1989) and various issues of the *Statistical Abstract of the U.S. Economy*. TFP growth rates are calculated using the private business sector data in Bureau of Labor Statistics (1991). "Other S&E" is the sum of scientists and engineers engaged in R & D for France, West Germany, and Japan.

A Simple Generalization

❖ C. Jones (1995) showed empirically that a constant growth rate appears consistent with *growing* innovative effort, not with a constant *level* of innovative effort

❖ Consider a generalization

$$\dot{A} = \delta A^{\phi} L_A^{\lambda} \;\Rightarrow\; g_A = \delta A^{\phi-1} L_A^{\lambda}$$

where ϕ captures how the current stock of ideas influences future idea production and λ captures potential crowding effects, where researchers may duplicate each others' work

❖ For steady-state growth, take logs and differentiate w.r.t. time

$$g_A = \frac{\lambda}{1-\phi} g_{L_A}$$

Implications for Growth

$$g_A = \frac{\lambda}{1-\phi} g_{L_A}$$

❖ Macro-evidence suggests $\phi < 1$, so that steady-state growth relies on exponentially increasing effort. (Steady-state growth with constant effort requires $\phi = 1$.)

- Corollary: If population growth halted, then productivity growth (and per-capita income growth) would slow and eventually stop

- Corollary: Allows limited increase in idea production *per researcher* along the growth path ($0 < \phi < 1$); perhaps even declining idea production per researcher ($\phi < 0$)

Digging Deeper:
Cumulativeness and the Creative Process

❖ Fishing Out (Kortum 1997)

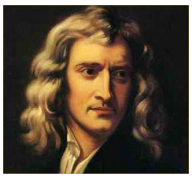
❖ Recombination (Weitzman 1998)

❖ Burden of Knowledge (B. Jones 2009)

Thinking especially about how current stock of ideas influences further idea production, based on particular views of the *underlying creative process*.

Cumulativeness and Human Capital

❖ We do seem to draw from evolving idea distributions. New theories, facts, techniques, and other complementary inputs that allow new insights or "new combinations" (e.g., Weitzman 1998)



"If I have seen further it is by standing on ye sholders of Giants."
- Isaac Newton

❖ But to use such knowledge, we first have to learn it. What happens if one must first climb up the Giants' backs?

❖ *Cumulativeness* may impose increasing *human capital* investment challenges on the young

- As frontier advances, educational burden may rise

The Burden of Knowledge

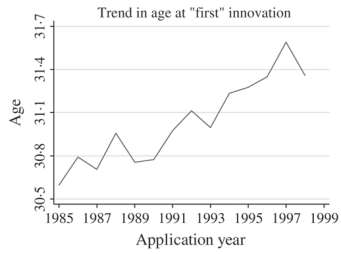
❖ What happens if new ideas, by creating new knowledge, imposes an increasing educational burden on future innovators?

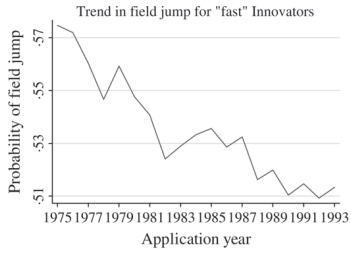
❖ Two margins of response
- Spend more time in training
- Choose narrower expertise

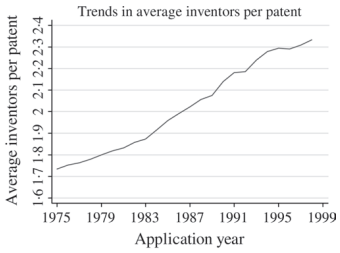
❖ Implications
- Individual innovators are less capable
  - Less time to innovate if more time in training
  - Harder to have broad impact if narrowing expertise
- Greater need for collaboration in research

The Burden of Knowledge: Some Evidence

❖ Micro-evidence from patent data (B. Jones 2009)

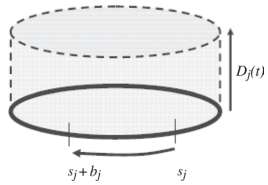






The Burden of Knowledge and Growth

❖ Focus on creativity effect of narrowing expertise. Consider a "circle of knowledge" with a continuum of knowledge types (indexed by *s* around circle) where depth of knowledge is *D(t)*



❖ Let educational attainment for innovator born at time *t* be their breadth (*b*) times the prevailing depth (*D*)

$$E(t) = b(t)D(t)$$

❖ Let creativity (for an individual) be

$$\dot{A} = A^{\chi} L_A^{-\sigma} b^{\beta}$$

The Burden of Knowledge and Growth

❖ Let the depth of knowledge follow the stock of existing ideas

$$D = A^{\delta} \Rightarrow g_D = \delta g_A$$

❖ In equilibrium, individuals choose educational expenditure as a constant fraction of lifetime income, *E(t)/y(t) = c*, implying

$$g_E = g_y = g_A$$

so individual educational attainment grows along the growth path at the same growth rate as the economy

This pins down how much you learn, and with depth of knowledge, how much you specialize

The Burden of Knowledge and Growth

❖ Growth rate of economy is

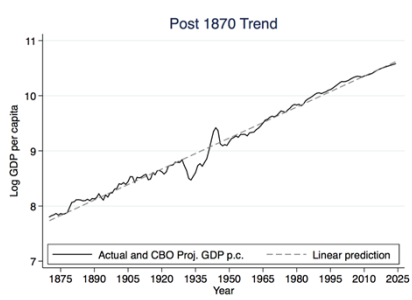
$$g_A = \frac{1-\sigma}{1-\chi+\beta(\delta-1)} g_{L_A}$$

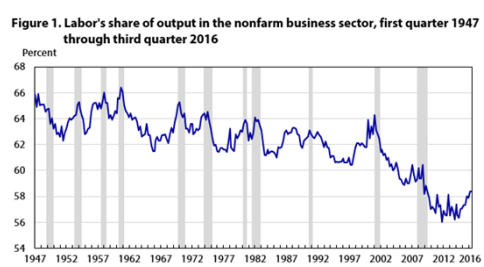
Relating to prior models, the crowding term is $\lambda = 1 - \sigma$, and the inter-temporal spillover term is $\phi = \chi - \beta(\delta-1)$

❖ With increasing specialization ($\delta>1$), we can now have rich idea possibilities (large χ) and yet still explain macro facts ($\phi<1$) because individual innovators see narrowing share

Growth: New Frontiers

❖ The fact of a constant capital share is under attack





❖ Separately, increasing interest in "automation" and artificial intelligence. How will these affect labor?

❖ Now seeing new growth frameworks, e.g., Acemoglu and Restrepo (2018), Jones and Liu (2022) that formalize automation process

The Social Returns to Idea Creation Take 2: Jones and Summers 2021

- If ideas are central to advancing prosperity, can we use macroeconomic arguments to reveal the overall social returns?
- The same kind of argument in Solow, which directs us to the advance of ideas as central to explaining rising standards of living, can also direct us to the social returns and policy.
- Let's look again at the social returns, but from a "big picture" macro perspective.

What Are the Social Returns to Innovation?

- To answer this question we must (a) measure the social benefits from innovation investment, and (b) compare these benefits to the investment costs.
- But assessing the social benefits of specific advances is super difficult.

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Social Returns and the Spillover Challenge

- The root measurement challenge is that society-wide gains seem to differ considerably from the private returns to the innovator and are fundamentally hard to trace.

- Numerous "spillover" margins; e.g.,
  - Imitative spillovers (+)
  - Business stealing (-)
  - Intertemporal spillovers (+/-)
  - Duplication (-)

- How can we estimate the social returns in light of these complex spillovers?
- And how can we avoid "picking winners" for these assessments, since innovation investments often fail?

Literature: Challenges

- Regression methods
  - Spillover boundaries?
  - Intertemporal spillovers? Lags?
  - Causation?

- Case studies
  - Successes only? What about failures?
  - What about advances with diffuse applications?

- Innovation investments that may be especially important seem especially hard to assess
  - Basic research
  - General purpose technologies

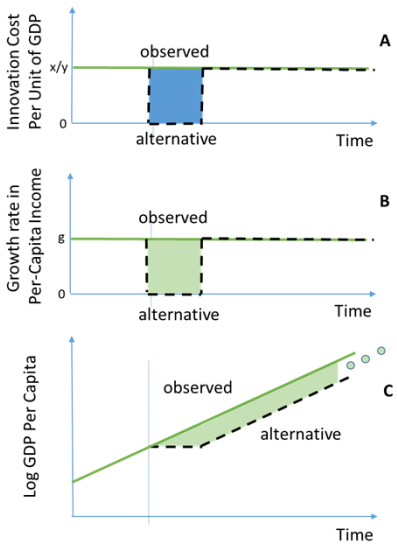
Jones and Summers (2021): Overview

1) Consider the *average* social returns to innovation
   - Examine path of GDP per capita to net out spillovers
   - Examine total innovation investment to capture success and failure
   - Produce baseline calculation, based on transparent and easily editable assumptions

2) Generalize the baseline -- reasons baseline may be too low, or too high

3) Consider distinction between marginal and average returns
   - Micro-founded arguments
   - Macro growth models

Baseline Calculation: Conceptual Model



Investment cost is x/y for one year

Benefit is g% higher income forever

Present value of benefit is g/r

Baseline Calculation: Conceptual Model

The *average* social returns are then

$$\rho = \frac{g/r}{x/y}$$

Present value of the benefits

Investment cost

Implications:
If x is R&D costs only, then average social returns appear enormous.
If x is incorporates all sorts of other investment costs, then the average social returns are still very large.

The "R&D Only" Baseline: Candidate Social Returns

Take $g = 1.8\%$ and $x/y = 2.7\%$ (U.S.)
Then the average social returns are:

Table 1: The Average Social Returns, by Social Discount Rate

Social discount rate (r)	Average Social Benefit-Cost Ratio (ρ)
1%	66.7
2%	33.3
3.5%	19.0
5%	13.3
7%	9.5
10%	6.7
67%	1

Extending the Baseline

The baseline calculation may be too high or too low.
Introduce the corrective factor, β.

$$\rho = \beta \frac{g/r}{x/y}$$

Baseline too high? ($\beta < 1$)

- Lags
- Capital investment
- Other sources of innovation

Baseline too low? ($\beta > 1$)

- Inflation bias
- Health gains
- International spillovers

Conclusions: Jones and Summers (2020)

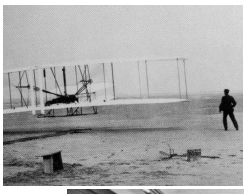
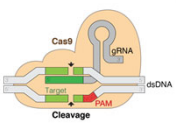
- A new approach, complementary to prior literature
  - Focus on the *average* return to innovation investments
  - Allows extensions to many potentially first-order issues
- Findings
  - Even under conservative assumptions, it is difficult to find an average return below \$4 per \$1 spent.
  - Middle-of-the-road estimate suggests \$10 per \$1 spent, and perhaps multiples higher
  - Marginal returns look somewhat lower, but not much lower

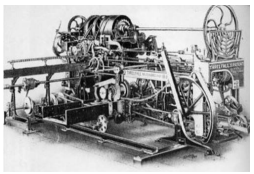
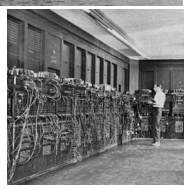
The Bigger Picture: Policy

❖ If the social returns are, on average, very large, what are the main market failures? What institutional structures and policies can overcome specific market failures? For example, how important is science and how can we can support science effectively?

The Really Big Picture

❖ How do you capture value from an idea? What role does science play in society? How does uncertainty affect idea production and exchange? How do strategic interactions influence idea creation? Where do big ideas come from -- who produces them, what kinds of creative processes do they use, and what incentives are effective?

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